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R C van Dijk

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Anmelder/Applicant(s)/Demandeur(s):

Philips Intellectual Property & Standards
GmbH
Steindamm 94
20099 Hamburg
ALLEMAGNE
Koninklijke Philips Electronics N.V.
Groenewoudseweg 1
5621 BA Eindhoven
PAYS-BAS

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Reconstruction of an image of a moving object from volumetric data

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DESCRIPTION

Reconstruction of an image of a moving object from volumetric data

The present invention relates to the field of digital imaging and in particular to three-dimensional art of diagnostic computed tomography (CT) imaging. In particular, the present invention relates to a method of reconstructing an image of an object from volumetric data of the object, to an image processing device and to a machine readable medium, having instructions recorded thereon.

In typical spiral or helical CT scanning, an x-ray source or tube emits a beam of radiation as it rotates continuously around an examination region, through which a patient support table moves at a constant linear velocity. Detectors positioned across the examination region from the x-ray tube, convert x-rays which traverse the patient into corresponding electronic data. The collected data effectively represent a helical path of constant pitch through the patient. The helical data, which may also be referred to as volumetric data, are reconstructed into a volumetric image representation, typically a series of consecutive thin slice images of a region of interest of the patient. Examples of such methods and apparatus are, for example, described in US patent numbers 5,544,212; 5,485,493; 5,262,946; and 5,396,418, which are hereby incorporated by reference.

Furthermore, there are a number of methods aimed at reconstructing cardiac images with reduced motion artifacts. For example: a prospective electrocardiogram (ECG) gated method with axial slice CT acquisition may be used to reconstruct cardiac images, such as, for example, described in US 5,751,782. A retrospective ECG-gate CT data acquisition and reconstruction technique using spiral CT is also known, as indicated, for example, in US 6,154, 516.

A particular problem in the CT of moving objects such as the heart or the coronary artery system is that different parts of these objects are at rest at different time points. Thus, a gated reconstruction with globally selected phase points for the moving or deforming objects are always a compromise, since, as described above, it may happen that areas of the object are with minimal motion, whereas other areas of the object have significant motion.

It is an object of the present invention to provide for an improved visualization of moving objects, such as, for example, the heart or the coronary artery section or parts of a coronary artery.

According to an aspect of the present invention, the above object may be achieved by a method as set forth in claim 1, where an image of an object is reconstructed from volumetric data of the object. The volumetric data include a plurality of projections corresponding to a plurality of time points. According to the method of this exemplary embodiment, a motion of the object is estimated. Then, first time points are determined, where the motion of the object is minimal on the basis of the estimated motion and projections are selected from the plurality of projections on the basis of these first time points. Then, the image is reconstructed from the projections selected from the plurality of projections.

Advantageously, due to the fact that the image is reconstructed from projections where the motion of the object is minimal, an improved image quality may be provided, where moving objects such as the heart may be reconstructed without blurring. Furthermore, due to the estimation of the motion, an automatic optimization of the image quality may be provided, since the selected projections correspond to time points with minimal motion in the object.

According to another exemplary embodiment of the present invention as set forth in claim 2, the volumetric data correspond to cardiac CT data and simultaneously measured electrocardiogram data. According to this exemplary embodiment of the present invention, a reconstruction of a series of low resolution 3D images of the heart

is performed, which cover the cardiac cycle, i.e. a series with different phase points. Then, the determination of the motion fields is performed for the series of low resolution 3D images. Such motion fields then describe the cyclic motion of the heart with a low spatial resolution. Then, time periods are determined from the motion fields at which selected areas of the heart are addressed. These time points are collected in a temporal map, which then contains optimal time points for each of the selected regions of the heart. Then, on the basis of this high temporal map, a high resolution image is reconstructed from projections corresponding to the time points of minimal motion in the high temporal map.

Due to the fact that the motion detection operates on low resolution images, a very efficient method is provided. Advantageously, this may allow to keep computational costs moderate.

According to another exemplary embodiment of the present invention as set forth in claim 3, the missing time points in the high resolution map are determined by interpolation. Furthermore, according to this exemplary embodiment of the present invention, a reconstruction of the high resolution image is performed, such that data gathered at a certain time point are used to reconstruct a first region of the heart, whereas data corresponding to another time point are used for reconstructing a second region of the heart.

In this context is should be noted that the term "time point" is not limited to "a point in time", but may also relate to phase points, relating, for example, to the cyclic motion of the heart or to time periods and a corresponding temporal window around each phase point.

According to another exemplary embodiment of the present invention as set forth in claim 4, the volumetric data correspond to the coronary artery region and simultaneously measured electrocardiogram data. Furthermore, according to this exemplary embodiment of the present invention, the image is reconstructed on the basis of an iterative reconstruction optimization.

Due to the fact that for the iterative reconstruction optimization, projections are used where there is only minimal motion in the coronary artery region, the reconstructed image may have an improved image quality.

According to another exemplary embodiment of the present invention as set forth in claim 5, the selection of the projections from the plurality of projections corresponds to a setting of a gating window. A variation of the gating window causes a reconstruction of a new image on the basis of the iterative reconstruction optimization in real-time. This image may then be displayed on a display. According to an aspect of this exemplary embodiment of the present invention, a gating window adaptation with respect to width and position is performed based on the motion fields, such that, e.g. each of the coronary vessels having different motion patterns throughout the cardiac cycle is reconstructed from data corresponding to its own individual point in time (or phase point of the ECG signal), where its speed of motion is minimal. This means that, according to this exemplary embodiment of the present invention, the reconstruction window or gating window is shifted to the minimum motion (rest) phase for a particular vessel section of interest, in order to achieve optimum image quality.

According to another exemplary embodiment of the present invention as set forth in claim 6, the variation of the gating window is performed on the basis of the motion fields or the magnitude of the motion, such that the gating window is automatically set to time points, where there is minimal motion in the object, such that the new image is automatically optimized.

Advantageously, according to this exemplary embodiment of the present invention, an automatic optimization of the image quality may be provided.

According to another exemplary embodiment of the present invention as set forth in claim 7, the variation of the gating window is based on an input by, for example, an operator, such that a real-time interactive optimization of the image is provided. In other

words, an image determined on a first gating window may be displayed to a user. Then, this window may be manipulated by the user in terms of position and width, using, for example, standard level or window mechanisms. Then, according to an aspect of this exemplary embodiment of the present invention, the reconstruction result is immediately updated, such that the user may interactively control the optimization process.

According to another exemplary embodiment of the present invention as set forth in claim 8, a segmentation of the coronary vessel tree is performed from the volumetric data, allowing for an image displaying the coronary vessel tree without disturbing neighboring areas.

According to an exemplary embodiment of the present invention as set forth in claim 9, an image processing device is provided, allowing for an improved imaging of moving or deforming objects on the basis of a determination of time points with a minimal motion and the reconstruction of the image on the basis of projections of the volumetric data corresponding to these time points.

Claims 10 and 11 provide further exemplary embodiments of the image processing device according to the present invention.

According to another exemplary embodiment of the present invention, a machine readable medium is provided, having instructions recorded thereon, configured to instruct a computer to perform the method according to the present invention. The instructions recorded on the machine readable medium may be written in any suitable programming language, for example C++. The machine readable medium may, for example, be a CD-ROM. Instead of being stored on a machine readable medium, the instructions (or the computer program) configured to instruct a computer to perform the method of the present invention may also be available from a network, such as the World Wide Web, from which they may be downloaded to image processing units, processors or any suitable computers.

It may be seen as the gist of an exemplary embodiment of the present invention that a magnitude of the motion of the object of interest is determined. Then, on the basis of the motion magnitude of the object (or an absolute amount of the motion), time points or phase points are determined at which the motion of the object is minimal, or where the object or an area thereof is at rest. Then, according to an aspect of the present invention, projections are used to reconstruct the image of the object, corresponding to the determined time points with minimal or no motion. Thus, according to an aspect of the present invention, a first region of the object may be determined from projections corresponding to a first time point, whereas a second region of the object of interest may be reconstructed from projections corresponding to a second time point. In other words, for reconstructing an image of, for example, the heart, data corresponding to different points in time may be used to reconstruct an image. The present invention may, in particular, be advantageous in conjunction with gated cardiac CT reconstruction or coronary artery imaging in multi-slice CT.

These and other aspects of the present invention will become apparent from and elucidated with reference to the embodiments described hereinafter.

Exemplary embodiments of the present invention will be described in the following with reference to the following drawings:

Fig. 1 shows an exemplary embodiment of an image processing device connected to a CT-scanner according to the present invention.

Fig. 2 is a flow-chart of a first exemplary-embodiment of a method of operating the device of Fig. 1.

Fig. 3 is a flow-chart of a second exemplary embodiment of a method of operating the device of Fig. 1

Fig. 4 is a flow-chart of a third exemplary embodiment of a method of operating the device of Fig. 1.

Fig. 1 shows a schematic simplified representation of an image processing device 2 connected to an input/output unit 4 and to a CT-scanner 6, according to an exemplary embodiment of the present invention. The image processing device 2 comprises a calculation unit 8, such as a computer including a processor and a memory. The computer tomographic CT-scanner 6 comprises a stationary gantry 10 which defines an examination region 12. Reference character 14 designates a rotating gantry, which is mounted to the stationary gantry 10. A source of penetrating radiation 16 such as an x-ray tube is arranged on the rotating gantry 14 for rotation therewith. The radiation source 16 may be collimated to produce a cone or fan-shaped beam of radiation 18, which passes through the examination region 12 during rotation of the rotating gantry 14.

Furthermore, there is provided a collimator and shutter system 20 for shaping the beam of radiation 18 and for selectively gating the beam 18 on and off. Also, the radiation beam 18 may be gated on and off by means of electronically switching the source of radiation 16. Reference character 22 designates an object support such as a patient couch, supporting the object to be scanned such that a region of interest of the object is at least partially within the examination region 12 of the CT-scanner 6. On the rotating gantry 14, on a position opposite to the source of radiation 16, there is provided a radiation detector 24. The radiation detector 24 is arranged such that it detects a substantial amount of the beam of radiation 18 emitted by the radiation source 16 after passing through the object in the examination region 12. Preferably, the radiation detector is a 2-dimensional detector array. Furthermore, the radiation detector 24 is mounted to the rotating gantry 14 for rotation therewith such that the radiation detector 24 rotates together with the radiation source 16 around the examination region 12. It is also possible to use a third generation scanner system, where the detector is focused on the tube.

During rotation of the rotating gantry 14 around the examination region 12, the object support 22 holding the object of interest thereon is translated along a central horizontal axis of the examination region 12. Due to this, the radiation source 16 and the radiation

detector 24 follow a helical path relative to the object of interest. Optionally, in an alternative embodiment, the support 22 may remain stationary while the stationary gantry 10 is arranged such that it is translated or otherwise moved relative to the object of interest such that the source of radiation 16 and the radiation detector 24 are displaced along the helical path relative to the object of interest during a scan.

During a scan, the radiation detector 24 is sampled at predetermined time intervals. The sampling results read from the radiation detection 24 are electrical signals, i.e. electrical data, which are referred to as projection in the following. A whole dataset of a whole scan of an object of interest therefore consists of a plurality of projections where the number of the projections corresponds to the time interval with which the radiation detector 24 is sampled. A plurality of projections together may also be referred to as volumetric data. Also, according to an aspect of the present invention, the volumetric data may also comprise electrocardiogram data.

The plurality of projections are transmitted to the image processing device 2, where they are read by means of the calculation unit 8. On the basis of the plurality of projections, the calculation unit 8 reconstructs slice images of the object of interest along a plane perpendicular to the central horizontal axis of the examination region 12. Instead of generating slice images, the calculation unit 8 may also be constructed to determine 3-dimensional images or animated representations where, for example, individual images are put together such that an animated sequence of images showing, for example, the periodic movement of the human heart is generated. The images can be out-put via the input/output unit 4. Furthermore, the input/output unit 4 allows an operator to manually control parameters of the scan in the CT-scanner 6 and the image processing device 2.

Reference character 26 in Fig. 1 designates a sensor attached to the thorax of a patient to be examined. The sensor 26 is connected to an electrocardiogram (ECG) 28 which is connected to the image processing device 2. Alternatively, instead of the ECG, other corresponding devices may be provided, such as suitable acoustic sensors or optical sensors.

The CT scanner may be a high temporal resolution cardiac CT scanner, a CT scanner generally suitable for cardiac scans, and/or a multi-slice CT (MSCT).

First exemplary embodiment

This first exemplary embodiment of the method according to the present invention will be described with reference to cardiac CT, but may also be applied to other moving objects.

As described with reference to Fig. 1, the CT data, namely the volumetric data, are acquired together with a simultaneously measured ECG. The simultaneously measured ECG may be used as a reference to select projections which correspond to a certain heart phase. Typically, the aim of such gating is to select the end-systolic or the end-diastolic phase of the heart, in order to minimize motion artifacts. This selection of the heart phase may be controlled by the so-called phase point.

Since the activation of the heart is not performed instantaneously, the period of rest may have a significant spatial variation. According to an aspect of the present invention, it was observed that the spatial variations are relatively smooth, such that an optimal phase point may be determined by using low resolution images. This will now be described in further detail with reference to Fig. 2.

Fig. 2 shows a flow-chart of the first exemplary embodiment of a method for operating the image processing device 2 of Fig. 1.

After the start in step S1 of Fig. 2, the method continues to step S2, where cardiac CT data and simultaneously measured ECG data are acquired. Then, the method continues to step S3, where an area of interest is selected from the CT data, which contains the heart. Then, in the subsequent step S4, a series of low resolution 3D images of the heart

is reconstructed. The low resolution 3D images are selected such that they cover the cardiac cycle. According to an aspect of the present invention, they may cover the whole cardiac cycle. The resolution of the low resolution 3D images may be only 25%, or even as low as 6 % of the resolution of the high resolution image finally reconstructed in step S8. The low resolution 3D images, each having a different phase point, may be reconstructed, as described in W. Kalender, "Computed Tomography: Fundamentals, System Technology, Image Quality, Applications. " Publics MCD Verlag, Munich, 2000, which is hereby incorporated by reference.

Then, the method continues to step S5, where motion fields are determined, which describe the inter-image motion of the heart. In other words, one or a plurality of motion fields may be determined, describing the motion of the heart between the images of the series of low resolution images determined in step S4. These motion fields describe the cyclic motion of the heart with a low spatial resolution. The motion fields may be determined as described in T. Schäffter et al., "Motion compensated projection reconstruction" Magn. Reson. Imaging, 41:954 – 963, 1999, which is hereby incorporated by reference. The magnitude of the motion may also be estimated from a mean absolute difference (MAD) between two templates (volume regions in these two templates) or any other suitable similarity measure.

Then, the motion fields determined in step S5 are used in step S6 to determine time points or time periods at which a motion of areas of the heart is minimal or where these areas are at rest. As already mentioned above, time points are not limited to "point in time", but should be understood as relating to time points, time periods and/or phase points of the movement. This may, for example, be done by subjecting the motion fields determined in step S5 to a thresholding operation. Thus, in other words, in step S6, for each slice, i.e. for each low resolution 3D image, an optimum point of time with a minimal motion in the respective area of the heart is determined.

Then, in the subsequent step S7, a list of time points/time periods is determined, at which the respective areas of the heart have minimal motion or are at rest. The missing time points may be determined by interpolation. Then, in the subsequent step S8, a high resolution image having full resolution is reconstructed using the optimal phase points according to the high resolution list for each region of the heart. This may, for example, be done as described in W. Kalender, "Computed Tomography: Fundamentals, System Technology, Image Quality, Applications" Publics MCD Verlag, Munich, 2000, which is hereby incorporated by reference. Then, the method continues to step S9, where it ends.

According to the above described method, the high resolution image may be determined from data determined at different points in time and at different phase points, since, for each region of the object, the optimal phase point/time point is used. Thus, advantageously, an improved image quality may be provided, where, for example, the whole heart may be reconstructed without blurring. Furthermore, according to the present invention, the optimal phase point for the respective regions of the heart are selected automatically. Furthermore, since the motion detection operates on low resolution images, the additional computational costs involved for detecting the optimal time/phase points are kept moderate. Thus, a highly efficient method is provided, allowing for an improved image quality. As mentioned above, the method may be implemented as a computer program and may be stored on a computer product such as a CD-ROM. However, the computer program may also be available from a network, such as the World Wide Web.

Second Exemplary Embodiment

The second exemplary embodiment of the present invention will be described with respect to coronary artery imaging in multi-slice CT. Multi-slice CT (MSCT) has great potential for becoming the modality of choice for a non-invasive diagnosis of coronary artery disease (CAD). As described with reference to Fig. 1, the CT data are acquired

along with an ECG signal. As may also be seen from the first exemplary embodiment, it is beneficial to adapt the reconstruction, i.e. the time window within the ECG signal/cardiac cycle, from which data are used for reconstruction for optimum image quality. The reason for the need for such adaptation is that for each of the coronary arteries, there is a different motion pattern throughout the cardiac cycle, i.e. each vessel (and potentially even each part of each vessel) has its own individual point in time or phase point where its speed of motion is maximal or minimal. This means that for a diagnostic inspection of each (part of a) vessel, the reconstruction window or gating window may be shifted to the minimum motion (rest) phase for this vessel section of interest, in order to achieve image quality.

According to this second exemplary embodiment of the present invention, a motion field is determined, describing the motion of the respective object of interest, i.e. the vessels between time frames. Time points or phase points are determined from the motion field at which the respective portions of the vessels are at rest or have minimum motion and then, an automatic or user-interactive optimization approach may be performed by centering the reconstruction image at such time points and performing the reconstruction of the image at these time points. This will be described in further detail with reference to Fig. 3.

Fig. 3 is a flow-chart of a second exemplary embodiment of the method for operating the image processing device 2 depicted in Fig. 1 according to the present invention.

After the start in step S20, the method continues to step S21, where volumetric data of the coronary artery region measured along with an ECG signal are acquired. The volumetric data along with the ECG signal form 4D data. Then, in the subsequent step S22, a sliding reconstruction is performed for the 4D data. This may, for example, be done by using a retrospective or prospective ECG triggering and a standard reconstruction window, which is shifted along the R-R time interval. This provides for a sequence of 3D reconstructions, which may, for example, be displayed as a 3D movie

via the display of the input/output unit 4 to an operator or user. Then, in the subsequent step S23, from these 3D reconstructions or images, the coronary vessel tree is segmented. This may, for example, be done by a region growing approach, starting from the aorta. By this, the coronary vessel tree is segmented as far as possible. Then, in the subsequent step S24, motion fields between the time frames, i.e. between the 3D reconstructions, are determined. Instead of the determination of motion fields, including a direction of the motion, it may be sufficient to determine an absolute value of the motion or a magnitude of the motion. The motion fields may, for example, be determined by using image registration approaches, such as, for example, template matching. From the motion fields, the local vessel velocity can be determined as a function of time for the fraction of the R-R interval, during which the radiation (the x-ray source 16) was on. In other words, for each part of the vessel, defined by a suitable neighborhood, suitable for diagnostic purposes, the time point of minimum motion is determined in step S25. Then, the reconstruction window used in the subsequent reconstruction is centered at that time point and the reconstruction is performed in step S26. Then, in the subsequent step S27, the areas of the vessel tree for which reconstruction was performed on data from different points in time, are combined for forming the image of the complete vessel tree.

In rare cases, it may appear that the adjacent vessel parts do not fit geometrically well enough together for curved reformat representation of the total vessel. This may happen due to the fact that adjacent vessel parts may have been determined from data measured at different points in time. In such rare cases, according to an aspect of the present invention, measures for smoothing the representation may be performed. Then, the method continues to step S28, where the image of the complete vessel tree is output to, for example, the user or operator via the display of the input/output unit 4 and then the method continues to step S29, where it ends.

Advantageously, this method allows for an automatic optimization of the coronary image quality.

According to an aspect of this second exemplary embodiment of the present invention, the reconstruction performed in step S26 may be automatically repeated for varying widths of the window. Then, from the results, the sharpest or crispest image may be determined or stored for later retrieval during, for example, a diagnostic inspection phase.

In a variant of this exemplary embodiment of the present invention, steps S23 and S24 may be omitted.

Third exemplary embodiment

As in the case of the second exemplary embodiment of the present invention, the third exemplary embodiment of the present invention will also be described with reference to a coronary artery imaging in MSCT.

Fig. 4 is a flow-chart of the third exemplary embodiment of the method for operating the image processing device 2 depicted in Fig. 1, according to the present invention.

Since steps S30 to S34 correspond to steps S20 to S24 as described with reference to Fig. 3, for a detailed discussion and description of steps S30 to S34 reference is made to steps S20 to S24 in Fig. 3, to avoid unnecessary repetition. As in Fig. 3, in a variant of this exemplary embodiment, steps S23 and S24 may be omitted.

After step S34, the method continues to step S35, where the volume rendered representation of the vessel tree determined in step S34 is displayed to a user or operator on the display of the input/output unit 4. Then, a select option is displayed on display of the input/output unit 4 to a user or operator for selecting a part of the vessel tree for further inspection by iterative reconstruction optimization. In other words, a select option is presented to the user via the display of the input/output unit 4, such that the user or operator may select a part of the vessel tree for which a more detailed image

should be determined. Then, the method continues to step S37, where the corresponding ECG signal and the window used for the initial iterative reconstruction optimization are displayed on the display of the input/output unit 4 to the user or operator. Furthermore, as indicated in step S38, a motion information determined on the basis of the motion field may be displayed to the user or operator via display of the input/output unit 4.

Then, in the subsequent step S39, a manipulation option is displayed to the user or operator, prompting the user or operator to manipulate the reconstruction window or gating window used for the iterative reconstruction optimization. The manipulation may include a variation of the position and/or the width of the reconstruction window. Then, after reading the input by the user, which the user may input to the image processing device 2 via a suitable keyboard or touch-screen of the input/output unit 4, the method continues to step S40, where the iterative reconstruction optimization is performed on the basis of the window manipulated in step S39. This iterative reconstruction optimization is performed in real-time. Then, in the subsequent step S41, the image reconstructed in step S40 is displayed on the display of the input/output unit 4. Thus, according to this exemplary embodiment of the present invention, the user may manipulate the reconstruction window in terms of position and width, using, for example, standard level and window mechanisms. Then, the reconstruction result is immediately updated, i.e. a new image is determined by performing the iterative reconstruction optimization with the new window, such that the operator may interactively control the optimization process.

Then, the method continues to step S42, where it ends.

According to a variant of this third exemplary embodiment of the present invention, the individual results together with, for example, the respectively used reconstruction window may be displayed so that the user may compare the results obtained for different reconstruction window settings.

Thus, according to this exemplary embodiment of the present invention, a real-time interactive optimization procedure may be provided, allowing for an optimum image quality, in particular if applied to the coronary vessels in MSCT.

With reference to Figs. 1 to 4, the present invention has been described by using exemplary embodiments. Individual features and method steps of the three embodiments described above may be combined and used and applied in combination with each other.

CLAIMS

1. Method of reconstructing an image of an object from volumetric data of the object, wherein the volumetric data include a plurality of projections corresponding to a plurality of time points, the method comprising the steps of:

- estimating a motion of the object;
- determining first time points where the motion of the object is minimal on the basis of the estimated motion of the object; and
- selecting projections from the plurality of projections on the basis of the first time points; and
- reconstructing the image from the projections selected from the plurality of projections.

2. The method of claim 1,

- wherein the volumetric data correspond to cardiac CT data and simultaneously measured electrocardiogram data;
- wherein a number of low resolution images corresponding to a heart region are reconstructed;
- wherein the number of low resolution images correspond to a plurality of phase points of the heart;
- wherein a plurality of motion fields is determined for estimating the motion of the object;
- wherein the determination of the plurality of motion fields is performed for the number of low resolution images such that the plurality of motion fields describe the motion of the object between the number of low resolution images;
- determining a high resolution map of second time points where the motion of the heart is minimal on the basis of the first time points;
- selecting second projections from the plurality of projections on the basis of the second time points; and
- reconstructing a high resolution image from the second projections.

3. The method of claim 2,

- wherein a first number of the first time points is smaller than a second number of the second time points and wherein the second number of second time points is determined from the first time points by interpolation; and
- wherein the reconstruction of the high resolution image is performed such that a first area of the heart in the high resolution image is determined from first portions of the volumetric data corresponding to a first phase point of the heart, and a second area of the heart in the high resolution image is determined from second portions of the volumetric data corresponding to a second phase point of the heart, the first phase point being different from the second phase point.

4. The method of claim 1,

- wherein the volumetric data correspond to the coronary artery region and simultaneously measured electrocardiogram data;
- wherein the image is reconstructed on the basis of an iterative reconstruction optimization; and
- wherein a plurality of motion fields is determined for estimating the motion of the object.

5. The method of claim 4,

- wherein the selection of the projections from the plurality of projections corresponds to a setting of a gating window;
- wherein, on a variation of the gating window, a new image is reconstructed on the basis of the iterative reconstruction optimization in real-time;
- wherein the new image is displayed on a display such that a real-time optimization is provided.

6. The method of claim 5,

- wherein the variation of the gating window is based on the first time points such that the gating window is automatically set to time points where there is minimal motion in the object such that the new image is automatically optimized.

7. The method of claim 5,

- wherein the variation of the gating window is based on an input from a user such that a real-time interactive optimization of the image is provided.

8. The method of claim 4, further comprising the steps of:

- performing a sliding reconstruction of the volumetric data;
- segmenting the coronary vessel tree from the volumetric data;
- wherein the determination of the plurality of motion fields is performed such that the plurality of motion fields describes motions of areas of the coronary vessel tree.

9. Image processing device, comprising:

- a memory for storing volumetric data, wherein the volumetric data include a plurality of projections corresponding to a plurality of time points; and
- an image processor for reconstructing an image of an object from the volumetric data of the object, wherein the image processor is adapted to perform the following operation:
- estimating a motion of the object;
- determining first time points where the motion of the object is minimal on the basis of the estimated motion of the object; and
- selecting projections from the plurality of projections on the basis of the first time points; and
- reconstructing the image from the projections selected from the plurality of projections.

10. The image processing device of claim 9,

- wherein the image processing device is a CT system suitable for cardiac CT;
- wherein the volumetric data correspond to cardiac CT data and simultaneously measured electrocardiogram data;
- wherein the image processor is further adapted to perform the following operation:
- determining a plurality of motion fields for estimating the motion of the object;
- reconstructing a number of low resolution images corresponding to a heart region;
- wherein the number of low resolution images corresponds to a plurality of phase points of the heart;
- wherein the determination of the plurality of motion fields is performed for the number of low resolution images such that the plurality of motion fields describes the motion of the object between the number of low resolution images;
- determining a high resolution map of second time points where the motion of the heart is minimal on the basis of the first time points;
- selecting second projections from the plurality of projections on the basis of the second time points; and
- reconstructing a high resolution image from the second projections.

11. The image processing device of claim 9,

- wherein the image processing device is a multi-slice CT system;
- wherein the volumetric data correspond to the coronary artery region and simultaneously measured electrocardiogram data;
- wherein the selection of the projections from the plurality of projections corresponds to a setting of a gating window;
- wherein, on a variation of the gating window, a new image is reconstructed on the basis of an iterative reconstruction optimization in real-time; and
- wherein the new image is displayed on a display such that a real-time optimization is provided.

12. Machine readable medium having instructions recorded thereon configured to instruct a computer to perform the following operation:

- estimating a motion of the object;
- determining first time points where the motion of the object is minimal on the basis of the estimated motion of the object; and
- selecting projections from the plurality of projections on the basis of the first time points; and
- reconstructing the image from the projections selected from the plurality of projections.

13. The machine readable medium of claim 12,

- wherein a plurality of motion fields is determined for estimating the motion of the object;
- wherein the volumetric data correspond to cardiac CT data and simultaneously measured electrocardiogram data;
- wherein a number of low resolution images corresponding to a heart region are reconstructed;
- wherein the number of low resolution images corresponds to a plurality of phase points of the heart;
- wherein the determination of the plurality of motion fields is performed for the number of low resolution images such that the plurality of motion fields describes the motion of the object between the number of low resolution images;
- wherein the instructions recorded thereon are further configured to instruct the computer to perform the following operation:
- determining a high resolution map of second time points where the motion of the heart is minimal on the basis of the first time points;
- selecting second projections from the plurality of projections on the basis of the second time points; and
- reconstructing a high resolution image from the second projections.

14. The machine readable medium of claim 12,

- wherein the volumetric data correspond to the coronary artery region and simultaneously measured electrocardiogram data;
- wherein the selection of the projections from the plurality of projections corresponds to a setting of a gating window;
- wherein, on a variation of the gating window, a new image is reconstructed on the basis of an iterative reconstruction optimization in real-time; and
- wherein the new image is displayed on a display such that a real-time optimization is provided.

ABSTRACT

Reconstruction of an image of a moving object from volumetric data

In the CT imaging of non-homogeneously moving objects such as the heart or the coronary vessel tree, there is a problem that different parts of the objects are at rest at different points in time. Thus, a gated reconstruction with a globally selected time point does not yield a sharp image of such objects. According to the present invention, a motion of the object is estimated, describing the motion of selected regions of these objects. Then, on the basis of the estimated motion, time points are determined, where these areas have minimal motion. Then, an image is reconstructed, wherein the data from which the respective regions are reconstructed, correspond to the respective time points, where the regions have minimal motion. Due to this, an improved image quality may be provided.

Fig. 2

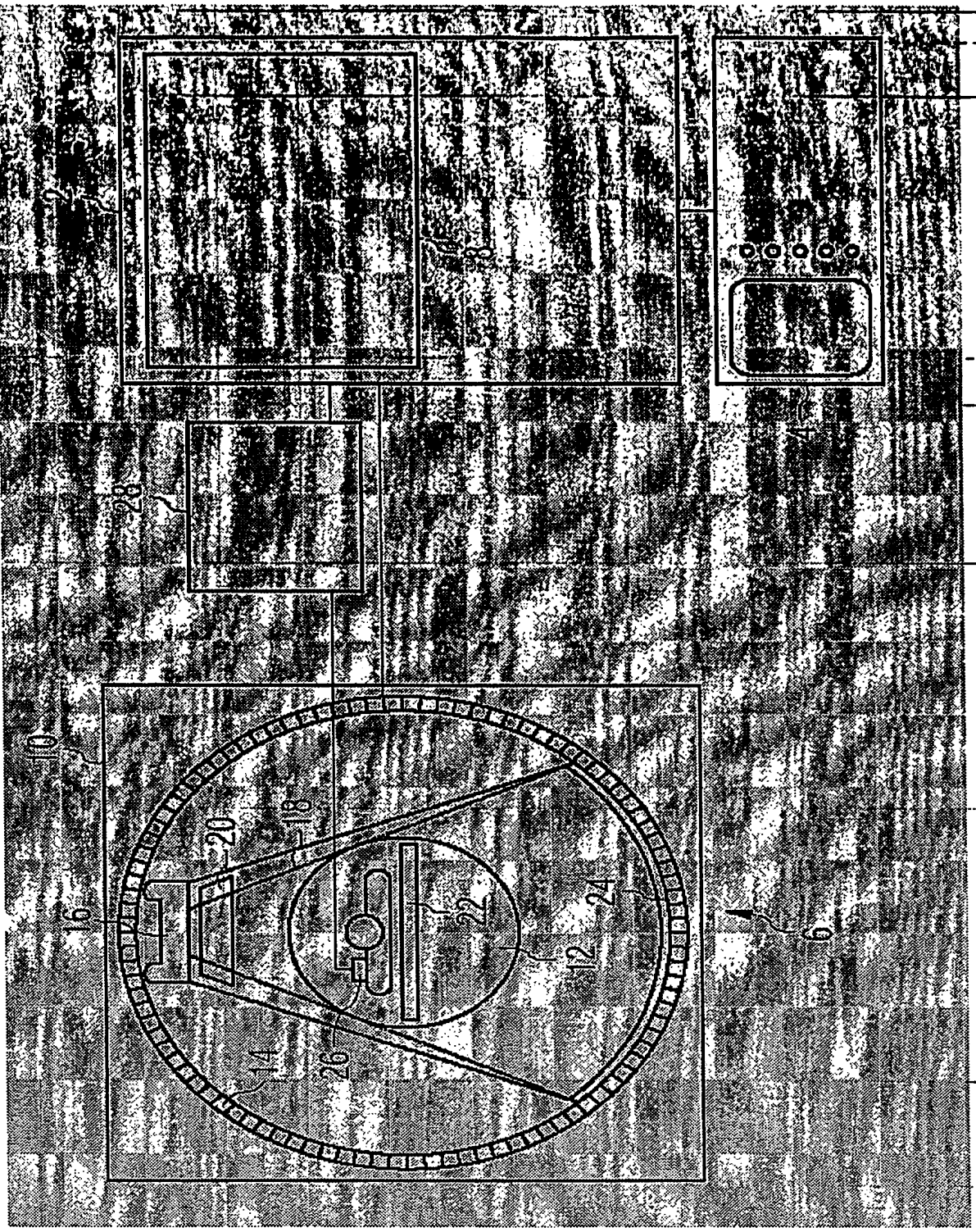

FIG. 1

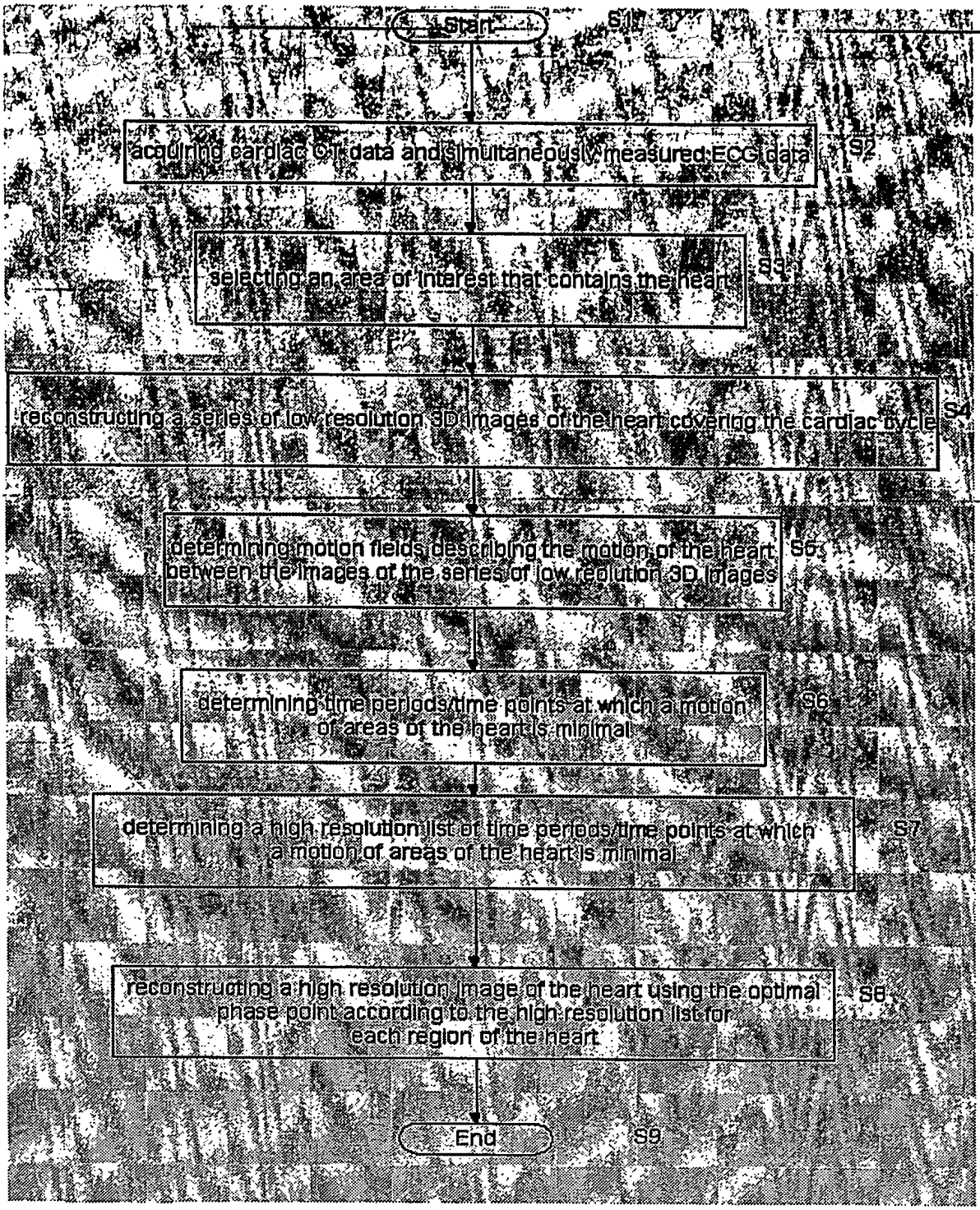
Start
S1
acquiring cardiac CT data and simultaneously measured ECG data
S2
selecting an area of interest that contains the heart
S3
reconstructing a series of low resolution 3D images of the heart covering the cardiac cycle
S4
determining motion fields describing the motion of the heart between the images of the series of low resolution 3D images
S5
determining time periods/time points at which a motion of areas of the heart is minimal
S6
determining a high resolution list of time periods/time points at which a motion of areas of the heart is minimal
S7
reconstructing a high resolution image of the heart using the optimal phase point according to the high resolution list for each region of the heart
S8
End
S9

FIG. 2

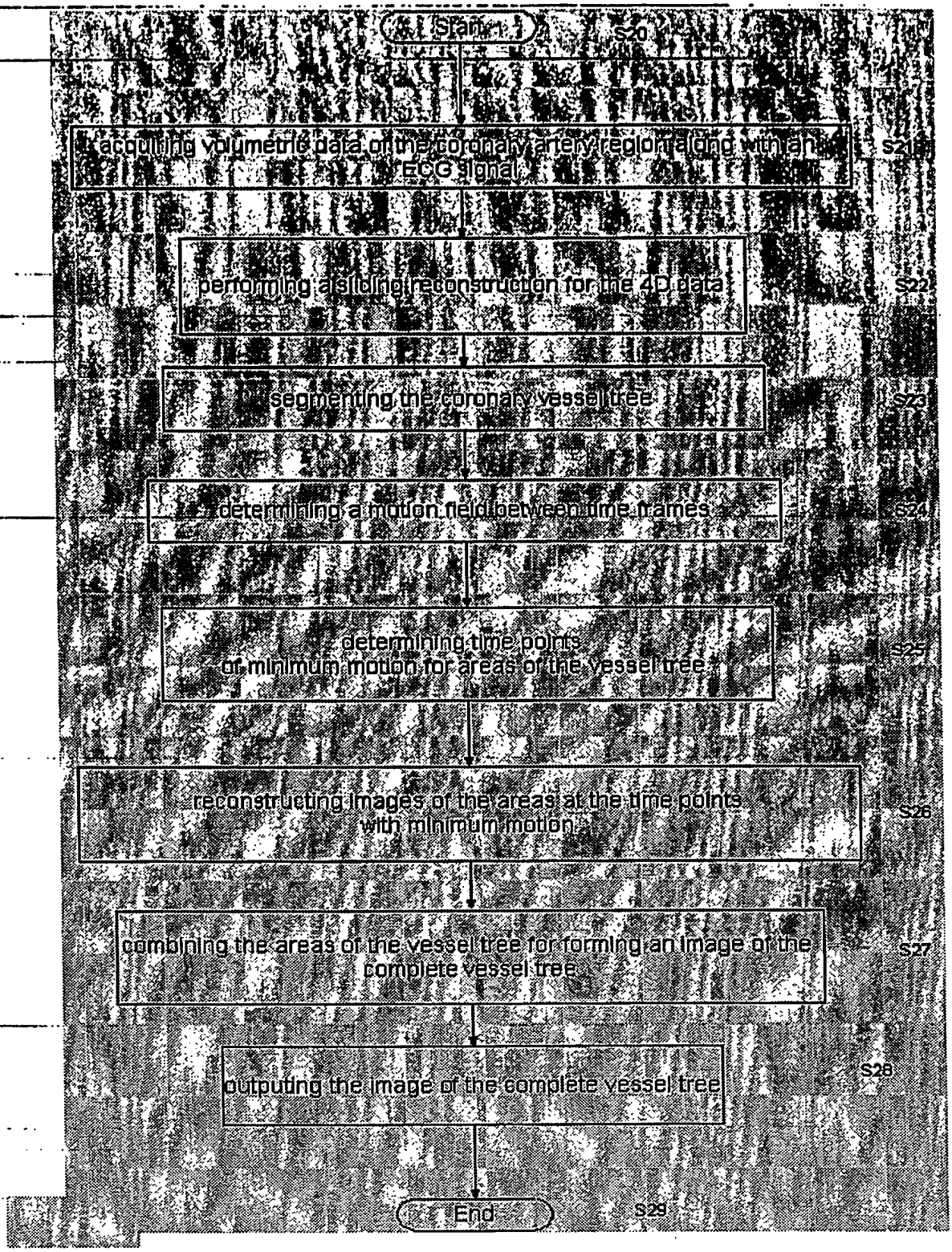
Start
S20
acquiring volumetric data of the coronary artery region along with an ECG signal
S21
performing gating reconstruction for the 4D data
S22
segmenting the coronary vessel tree
S23
determining a motion field between time frames
S24
determining time points of minimum motion for areas of the vessel tree
S25
reconstructing images of the areas at the time points with minimum motion
S26
combining the areas of the vessel tree for forming an image of the complete vessel tree
S27
outputting the image of the complete vessel tree
S28
End
S29

FIG. 3

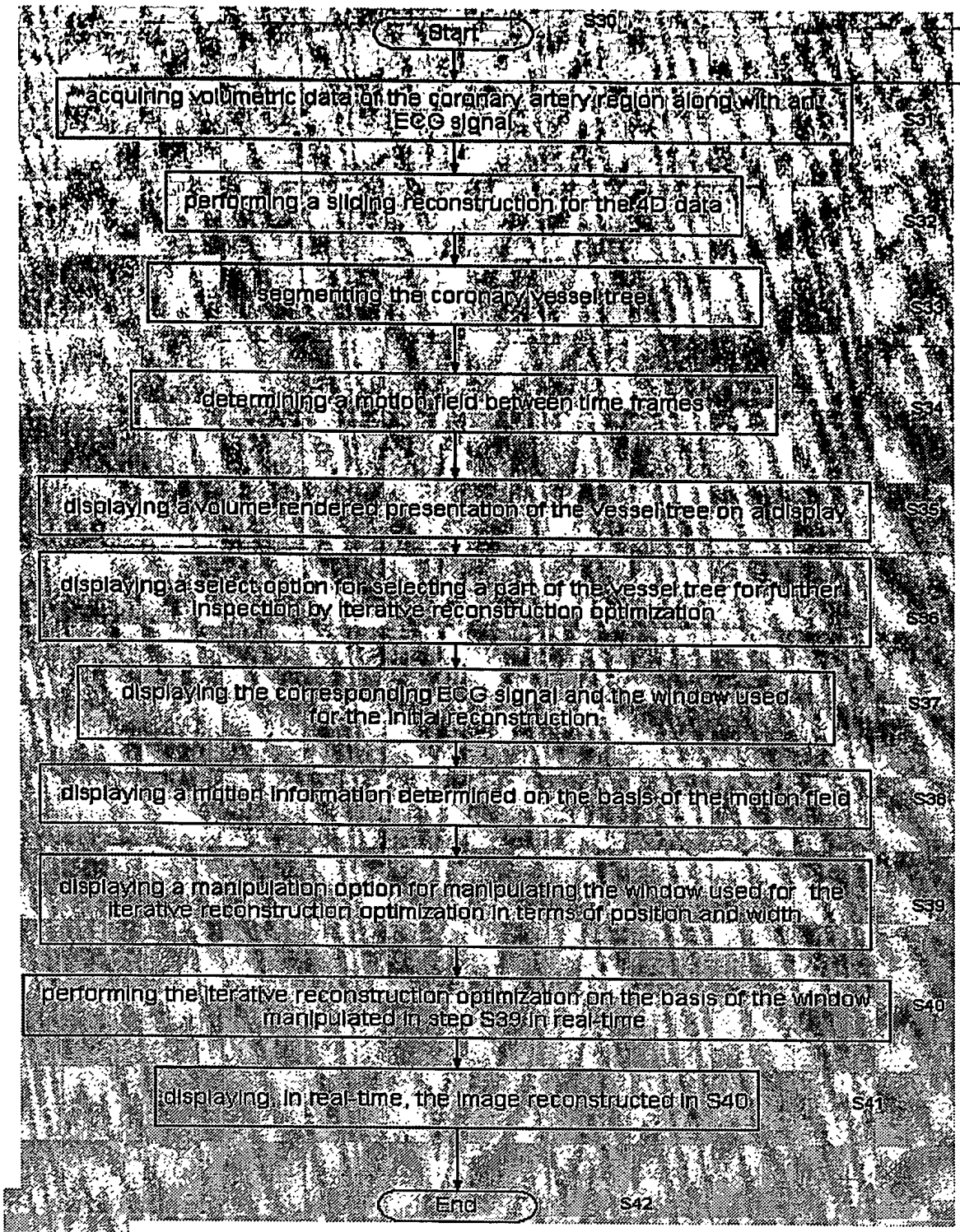
Start
S30
acquiring volumetric data of the coronary artery region along with an ECG signal
S31
performing a sliding reconstruction for the 4D data
S32
segmenting the coronary vessel tree
S33
determining a motion field between time frames
S34
displaying a volume rendered presentation of the vessel tree on a display
S35
displaying a select option for selecting a part of the vessel tree for further inspection by iterative reconstruction optimization
S36
displaying the corresponding ECG signal and the window used for the initial reconstruction
S37
displaying a motion information determined on the basis of the motion field
S38
displaying a manipulation option for manipulating the window used for the iterative reconstruction optimization in terms of position and width
S39
performing the iterative reconstruction optimization on the basis of the window manipulated in step S39 in real-time
S40
displaying, in real-time, the image reconstructed in S40
S41
End
S42

FIG. 4

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